STUDY CASE: REFURBISHMENT OF THE GARE MARITIME IN BRUSSELS

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ABSTRACT: This paper presents the study case of the Gare Maritime, a former train station in Brussels in Belgium that covers an area of 40.000m² and that has been entirely renovated to welcome under its roof the construction of twelve multilevel pavilions in fully timber structure. Those 4500 m² of twelve new buildings are hosting shops, publics functions and offices and creates a new covered quarter inside the city. This paper introduces first the project, its historical context, its situation and its refurbishment.

Then an explanation of the structural design is given and divided in different parts. A focus is first made over the specific features of the project to explain the challenges of the structure. Then the joints developed on the project are explained explaining the main type of assemblies. Thirdly, all the fire engineering process of the project is described; how the dossier was accepted by the authorities, the simulations and calculations that needed to be done. The last section finally gives information about the mounting process and the upstream preparation that it required. In the next chapter, more can be learned over the innovative technologies that have been implemented on the project to make it completely energy neutral and fossil free before finally concluding and giving some important numbers over the project.

KEYWORDS: Cross-laminated-timber, Glulam, Refurbishment, Collaborative ribbed floor; Thermal analysis.

1 INTRODUCTION

The "Gare Maritime", located on the site of Tour & Taxi in Brussels, is a former railway terminal, built in the early 20th century) by architects Constant Bosman and Henri Vandeveld and engineer Frédéric Bruneel.

Figure 1: *Front facade of the Gare Maritime*

It was once Europe's largest railway terminal but the development of road transport and the gradual removal of European customs barriers reduced activities to the point where this 40,000 m² area (276 by 138 m) was completely abandoned. For many years, it has been vacant and deteriorating. In 2014 a real estate developer bought the site Tour & Taxi and began transforming the storage halls and customs buildings around and to transform step by step the neighbour into a greener quarter.

Figure 2: *Ground floor plan*

The former station reaches a maximum height of 23 m. The load bearing structure consists largely of three-hinged frames, made of riveted metallic trusses, covering a 26 meters span. In this magnificent historical hall that has been renovated and reinforced, the Neutelings-Riedijk Architecten's office has inserted twelve four levels pavilions in timber structure with a total of 45.000 m². They will host shops, offices and public functions to make the Gare Maritime a real covered city. The structure of these interior volumes is entirely made of wood. In each of the lateral naves, 5 pavilions fit perfectly into the existing structure, making a total of 10 almost identical pavilions. At the front, 2 additional small pavilions

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complete the entrance and the central hall remains an free, covered avenue that can be used for events, sports and arts.

Figure 3: *Elevation*

1.1 RENOVATION PHASE

A first phase of the project was to renovate and reinforce the structure where necessary and to renew the building envelope to contemporary standards. The steel structure was overall in good condition, except for some damaged and corroded elements in the rear façade and under the gutters. One of the important points in the renovation of the structure was to be able to add solar panels on the existing roof. This was possible with a small amount of reinforcement as the structure still had some reserves of strength. Only some elements had to be replaced and there was some strengthening needed on elements that had potential for buckling.

An expertise of the wooden roof frame was also carried out. Some parts were attacked by fungi and had to be completely replaced. However, the expertise and the implementation of a monitoring system to ensure that the wood was properly dried out made it possible to preserve the existing wooden deck as much as possible. The refurbishment focused on a safe structure in accordance with current standards, with maximum respect for the initial project.

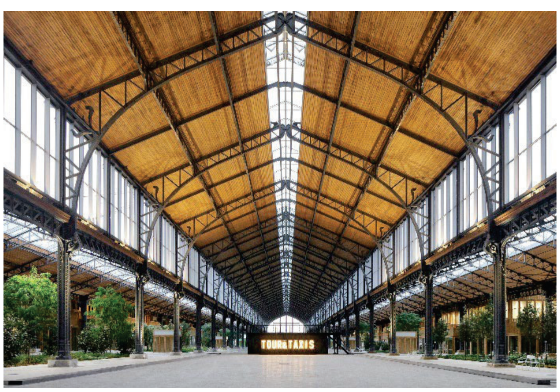

Figure 4: *Interior view of the refurbished naves*

1.2 THE CHOICE OF MATERIAL

At the start of the project, various structural concepts were proposed to the project owner (real-estate developer Extensa) and, for each one, the grid they suit best and their advantages. Those concepts were made of concrete or steel as well as wood.

However, it soon appeared to us that a timber solution was the most adapted proposal in the case of the Gare Maritime and the client was soon convinced too.

First, there was a strong desire from the design team to make the Gare Maritime a pioneering project in line with the existing structure. The aim was therefore to make it an example in terms of sustainability and circularity. The design of a mechanically assembled wooden structure makes it completely removable. Moreover, 1 m³ of wood on the project represents approximately 1 metric tonne of stored CO_2. We can also ensure that the wood is certified and comes from sustainably managed forests. Secondly, the demand was to build these 45,000 m² in a really short term. A fully prefabricated structure was the most appropriate way to meet this requirement. Further, it was important to work with relatively light elements. The idea was to limit the impact of the new structure regarding the existing foundation but also to be able to work with small and light machines since the structure is entirely covered, making it impossible to use traditional cranes.
Lastly, since the whole construction site was protected from weather conditions, the situation was ideal for a timber construction.

2 STRUCTURAL DESIGN

One of the challenges for this project was to integrate the 12 new buildings inside the existing historic hall. All the buildings are close to the existing building but remains completely independent of it. The connections between the new and the old building had to consider the thermal expansion of the historic framework. A 7cm gap had to be leaved between the two structures. As a result, there are many cantilevers in each pavilion so that the new structure meets the old one without being fixed to it.

The cores are made of cross laminated timber (CLT) and completed with columns-beams structure and with ribbed floor in glulam and CLT. Walkways and cross stairs connect pavilions to each other's.

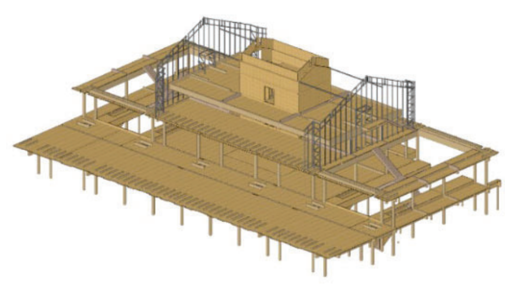

Figure 5: *3D model of one pavilion made with Cadwork [1]*

2.1 SPECIFIC FEATURES

Neutelings Riedijk Architects decided to work with a plan based on a grid of 1.2 by 1.2 m, ideal for the development of offices and perfectly fitting the existing grid of 12 m between the main steel structures. The structure was developed on this concept. All the floors are collaborative screwed ribbed floor composed by a CLT-100 panel that is screwed with glulam ribs every 1.2m. This type of floor

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allows to reach bigger spans (up to 8.4 m in this project) while optimizing the volume of wood.

At the beginning, the ribs were supposed to be glued to the CLT panels at the factory but Ney worked with a German timber company (Zublin Timber) on this project and this system would have made transportation from Germany to Brussels very inefficient. The possibility of setting up a workshop to do the gluing on site was considered by the company but the cost was prohibitive. This is why a screwed connection was designed instead.

To solve the cantilevers, the presence of a raised technical floor has been used to implement ribs on the upper side of the CLT. Thanks to this system, users of the buildings have the feeling that only a 10 cm thick CLT slab goes up to the existing structure.

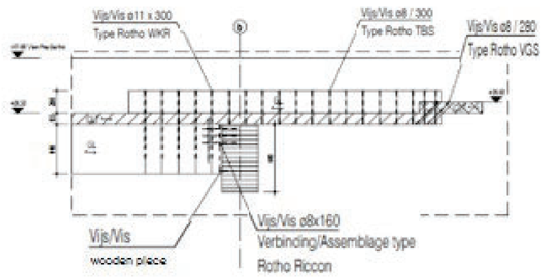

Figure 6: *Reversed collaborative ribbed floor in cantilevers*

To limit the number of holes in the timber elements and to facilitate de mounting, most of the techniques were also integrated under this raised technical floor. But on the ground floor, due to the presence of existing foundation, it was not possible to excavate too much to create a raised floor. An important number of holes had to be made in the ribs to offer flexibility for the future tenants so that they can install techniques in the ceiling. Each hole had to be reinforced by fully threated screws in the ribs.

It was important for the architect to design a structure completely made of wood. To be able to do it, in some areas where we were limited in height and where the stresses were particularly high, spruce LVL (Kerto) and beech LVL (Baubuche) beams have been used for their better mechanical properties. This is the case for the 16.5m long beams that cantilever by 4.8m to support the mezzanine on the third floor and that are made of laminated veneer spruce. The architect chose to clad them to keep the project homogeneous.

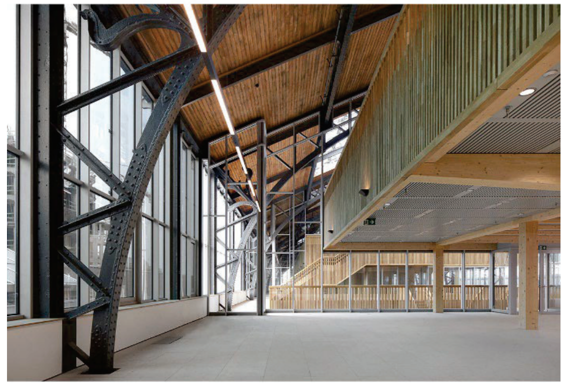

Figure 7: *Mezzanine on cantilevered LVL beams*

2.2 JOINTS

Nearly all joints remain visible on the project. The aesthetics of the connections has therefore been a key point in the design. The ribs on the second and third floors are assembled with concealed connectors using the principle of sliding dovetail joints made with a steel connector.

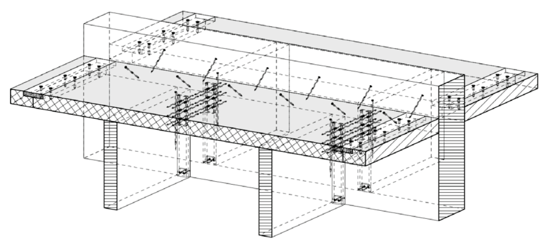

Figure 8: *Ribs connections*

In order to avoid compression problems perpendicular to the grain. Large steel profiles ensure direct load transmission between columns.

For the most heavily loaded beams, an HSK system has been used. These are perforated steel plates (HSK plates) moulded into the wood and glued with epoxy resin ensuring that they remain completely invisible. Those specific joints have also been used the ensure the continuity of the glulam stair stringers.

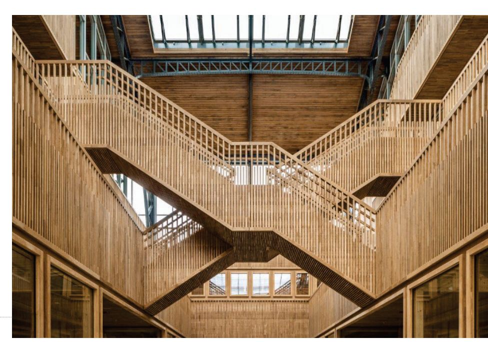

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Figure 9: *Crossing stairs between pavilions using HSK joints*

2.3 FIRE

A big topic on this project was fire safety. It was difficult for the renovation project to comply with existing fire safety Belgian standards and a derogation file had to be drawn up. For example, Belgian fire safety laws require evacuation stairs to be enclosed to protect against fire and smoke while the architect's intention was to work with open staircases.

Thus, several compensatory measures and solutions hade to be integrated in order to be able to execute such a project. Adapting thermal heat scanners used by the US military are used to act as fire detection, crossing stairs between pavilions were designed to act as evacuation stairs, 800 ventilation stacks were added along the existing roof ridge to help with air circulation as well as smoke extraction in case of fire. In addition to those solutions, a modelling of various escape scenarios and simulations of temperature and smoke evolution made by a fire engineering office were necessary to convince the authorities to approve the unconventional solution.

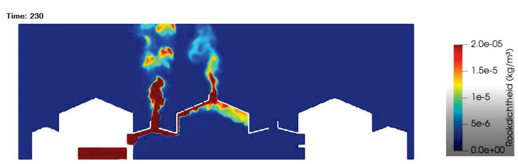

Figure 10: *Simulation of the smoke density*

Concerning the timber structure, an advanced study for fire stability has been performed for this project in collaboration with the University of Liège. Indeed, we were asked to demonstrate that the structure could withstand a longer period of time than originally planned while maintaining the same sections.

When necessary, it was chosen to work with an intumescent transparent paint specially developed for wood. Many products exist on the market to improve the fire reaction of wood but it was not easy to find a paint that improves the fire resistance with technical datas to understand how to calculate the impact of this painting over the timber section during fire. The painting found had valid datas for a floor with a certain load and span. As these assumptions were not met, the project configuration was tested to validate that the values used were still applicable and so a fire test on a real scale mock-up of the floor has been performed in order to validate the complex.

In addition to the fire test, we did further numerical analysis.
A finite element modelling of some joints has been done with the software SAFIR [2] to perform thermal and mechanical analysis and study the behaviour of those joints after a determined time without any protection or with de addition of an intumescent paint.

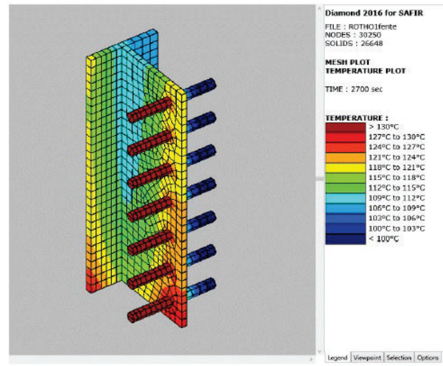

Figure 11: *Thermal analysis of a joint*

In case of fire, the behaviour of the timber depends not only on the temperature of the material but also on the type of solicitation (tension, shear, …). To be able to determine the load bearing capacity of a dowel, we modelled a beam (the dowel) supported by stiffeners whose stiffness varies along the dowel according to the evolution of the mechanical properties of the wood. The stiffener was thus representing the behavior of the wood depending on its temperature.
With the first general model of the joint, we knew the temperature of the wood along the cross section of the beam so we were able to characterize the stiffeners along the dowel. Then we applied at the position of the slotted plate a load that was incremented until the load bearing capacity of the dowel was reached.

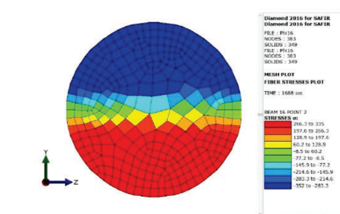

Figure 12: *Mechanical analysis of a dowel in case of fire: stresses in the dowel.*

2.4 MOUNTING

One of the biggest challenge of this project was the great volume of timber alongside the very short programme. The project's extensive scale, the need for precise integration of new elements into the existing structure and the tight deadlines were crucial factors in choosing a BIM process.

Timber construction is undeniably linked to a high degree of prefabrication. The entire structure was then already designed based on a 3D model drawn with software specialized in timber construction. This makes it possible to integrate this BIM process that is conducive to prefabrication, from the designer to the erector via the supplier, and so on.

The contractors were also required to build a two-storey, full size mock-up on site. This mock-up had to integrate the timber structure, oak siding, steel façade and technical equipment in detail. As part of the project requirements, the contractors were tasked with constructing a full-scale mock-up on site, consisting of a two-storey structure that meticulously incorporated timber elements, steel façade, oak siding and technical equipment.

On one hand, being under cover eliminated any weather dependency during construction. But on the other hands, the new buildings had to be closely integrated into the existing structure – with limited room for manoeuvre. The use of traditional cranes was not possible and the assembly of all the elements and the phasing with the techniques had to be carefully studied.

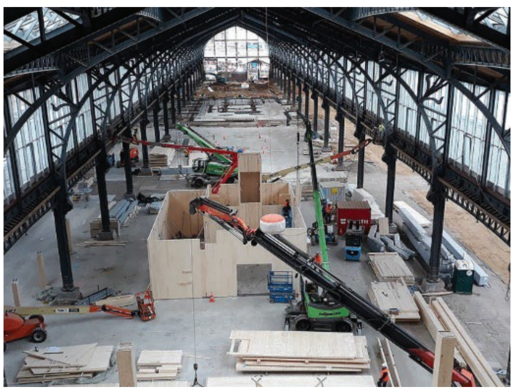

Figure 13: *Construction of the CLT core*

Finally, thanks to the BIM, all the elements were prefabricated, and the construction of the timber structure was extremely fast. It took in average 8 weeks to build 1 pavilion. It means the logistics of delivery and storage of the many pieces had to be tightly managed. The timber structure was fully executed in 10 months, only 14 months after the timber constructor signed the contract.

Figure 14: *Mounting of one pavilion*

3 MODERN AND INNOVATIVE TECHNOLOGIES

The original building has been preserved, including the wood and steel roof, while integrating modern and sustainable technologies for this high energetic performance project. Indeed, the Gare maritime is entirely energy neutral and fossil free.

In addition to CO2 stocked into the volume of wood, sustainability measures have been implemented.

On the roofs a total area of 17 000 m² of solar panels has been installed. The solar technology can also be found in the form of cells integrated into the windows on the south façade of the building. 140-metre deep boreholes were drilled between the pavilions into the bedrock and a subterranean lake system. The then probes are able to provide heating and air conditioning of the space by geothermical energy.and a rainwater recovery system has been installed on the 4 hectares of the roof to maintain the interior gardens and sanitary facilities.

Each pavilion is a highly insulated house underneath the existing envelope. This way, it was not necessary to heat the entire hall. The lateral skylights feature thus triple glazing only in the areas bordering the ten pavilions.
In addition to insulating the offices, Halio's smart tinting glass is used to enhance lighting management of the building. The glass begins tinting within seconds and reaches full tint in less than 3 minutes. It manages not only the intensity of light but also solar heat. Using electrochromic technology, this interactive glazing uses an electrical impulse to switch from total transparency to a dark tint, reducing glare. The glass then transforms into a virtually opaque surface, allowing only 3% of light to pass through. The privacy of the occupants is preserved without cutting them off from the outside environment.

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4 CONCLUSIONS

In just three years, the entire 40 000m² of the former railway station underwent a complete renovation, resulting in its transformation into a covered, climate neutral quarter in the heart of Brussels city.

The Gare Maritime now houses a fully wooden structure with a total of 9000 m³ divided into 3000 m³ of glulam and 6000 m³ of CLT. This made the Gare Maritime one of the largest timber projects in Europe when it was inaugurated in September 2020. Since its completion, the project has won several awards, among them in 2020 the Dutch ARC20 Architecture Award, the Belgian Timber Construction Award and the RES Award, and in 2021 the Belgian Building Award, the Europa Nostra Award, the MIPIM Award and the ULI Europe Award for Excellence.

The covered city has now transformed into a bustling hub of various activities, welcoming day workers and visitors. In the evenings and at weekends, the activity continues thanks to its food market and the events held there, such as the world padel tour, which will be held there in 2023 for the second year running.

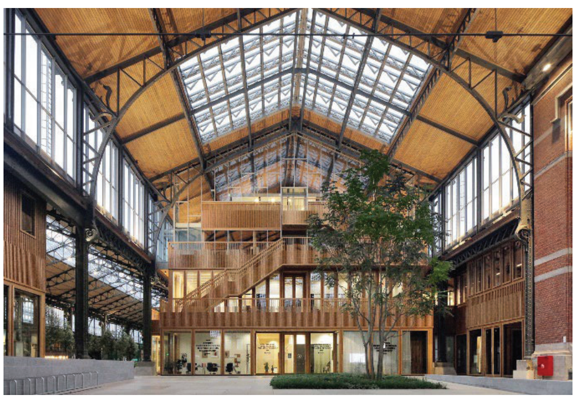

Figure 15: *View of one pavilion inside the existing structure*

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